Proceedings of IOE Graduate Conference, 2019-Winter
Peer Reviewed
Year: 2019 Month: December Volume: 7
ISSN: 2350-8914 (Online), 2350-8906 (Print)

Power Flow Management for EV Charging at Charging Stations

Dol Raj Kunwar [a], Bijay Sharma [b], Sunil Paudel [c], Tanka Nath Ojha [d], Menaka Karki [e]

[a, b, c, d, e] *Department of Electrical Engineering, Pashchimanchal Campus, Institute of Engineering, Tribhuvan University, Nepal*
Corresponding Email: [a] astodsk38@gmail.com, [e] menaka@wrc.edu.np

Abstract
Electric Vehicles (EVs), being fueled by electric power, are going to rule over the conventional vehicles. They do not depend on the petroleum products and do not produce carbon emissions which has high threat to the environment. To realize electric locomotion, there should be efficient charging facility in our electrical infrastructure to charge the batteries of the EVs. This work proposes an effective topology that focuses on how the batteries of EVs receive electric power. The EV owner can charge his vehicle up to desired SOC level from direct solar PV system installed on the rooftop or the grid or the Battery Energy Storage System (BESS). Here, BESS is a massive energy storage system that can store energy from the grid as well as from the PV system. BESS supplies the load during the peak of the system and helps the system relieve during peak hours. Regulation of EV load sharing and prevention of mismatch between circulating currents supplied by power sources is implemented using fixed droop method. The trend of power demand of EVs throughout a day in a charging station is taken from a reference. The simulations are successfully implemented to validate the effectiveness of the system and to demonstrate the load management. The overall system is implemented by algorithm run in MATLAB/Simulink.

Keywords
Electric vehicle charging; power flow management, Droop method

1. Introduction

Currently,transport sector faces significant challenges regarding the energetic model based on oil products. In fact, 65.3 % of the oil consumed in the world in 2016 was due to the transport sector, which caused emissions of 6892 Mt of CO_2 into the environment [1]. This dependence and the excessive use of oil entails numerous issues: environmental problems such as climate change and pollution in large cities, economic problems due to rising oil prices and geopolitical problems due to the instability of the producing countries and oil use as economic weapon. In this scenario, electric vehicles (EVs), could be a sustainable alternative to internal combustion engine vehicles. Adding much advancement and technology, the electric vehicles can be charged using solar power via photovoltaic cells (PV). So here EVs can avoid using first person. can appropriately use the combination of solar power and grid power.

The EVs draws electricity from battery from charging station in which the interconnected grid is present along with PV. Thus, many countries have been introducing the EVs as their way of transportation. But the limitations for this concept is that there is the problem of slow charging thus the time problem is quite bulky. But this can be solved with the proper scheduling.

The main objective of this paper is to manage different power sources (PV, battery and grid) in accordance with varying load demand from electric vehicle. Power flow from the sources is to be managed such that the first load sharing priority is given to the PV in order to utilize all the available power of the PV. Electric vehicle can be charged with constant or variable power supply. Charging with variable power supply is less efficient. Constant power charging is necessary for EVs battery to reduce polarization. That's why charging with constant power is prominent. Reference [2] proposed the charging processes in uncoordinated and coordinated manner. In uncoordinated charging, the charging process is performed at on-board charger power rating without any control. Coordinated charging meets the expectation of both the utility operators and EV users.

A study [3] had proposed smart charging, which contributes in peak shavings and valley fillings. The centralized and decentralized control strategies are also proposed as the methods of smart charging.

Grid tied PV-battery hybrid technology is proposed by [4], which supports the reduction of the stress on the grid line due to overloads. A probabilistic model has been proposed by [5], which presents complete mobility patterns of EVs in order to estimate an expected load in the system to illustrate rigorous power quality index that may be used by utilities to upgrade their infrastructures supporting large penetration of EVs. Simulation and analysis of photovoltaic system with boost converter is proposed and presented by [6] where the integration of dc-dc boost converter with PV is done and the voltage is made almost constant by using PID Controller. Similarly, reference [7] proposed multi-source model and developed a control algorithm for EV charging. It also presented real time monitoring of power demand and supply. To reduce stress in the grid, power demand by EV is supplied by PV and Energy storage system (Battery) by adopting an optimization algorithm, where priority wise selection of sourced is implemented. When multiple power sources are connected in parallel for supplying common load, the load sharing in dc power system is to be regulated. Reference [8] proposed current sharing control of parallel boost converters based on droop index. Droop regulation method for load sharing has been commonly used in different literatures.

This paper presents the MATLAB simulation model of power management strategy among PV, BESS and grid at different times of a day for electric vehicle charging. The proposed strategy is based on the uncoordinated charging method of electric vehicle in which power sources are managed for providing all the demand of EV loads. This paper focuses on to the use of RES for reducing the stress on the Grid due to high power demand from electric vehicle for charging.

2. Modeling of components

2.1 Modeling of PV, BESS and Grid

1. Photovoltaic Array: The power output from the PV depends on irradiance and temperature conditions. The model of PV array available in MATLAB is used and is operated with various values of temperature and irradiances. Number of modules connected in series and parallel determines its rating (maximum power). Pv array is modeled with rating such that it could provide the base load demand in the charging station, which is estimated to be 28kW. For providing base load, 8×17 PV pannel with the maximum output voltage and current rating of PV is 240V and 120A is used. The PV arraay is connected to the DC link via boost converter with PID control to match the voltage output of PV with DC link voltage. The another purpose of using PID controller is that it makes converter output voltage follow the reference voltage provided by load sharing algorithm.

2. Battery Energy Storage System: the Battery storage system should provide the base power demand of 28kW during the peak load period. The rating of storege should be 140 kWh for providing load continuously up to 5 hours when full charged. BESS is connected to the DC link via its boost converter along with PID controller in the same way as PV is connected. The charging and discharging of battery is controlled though a switch operated by power management algorithm.

3. Grid: Grid delivers the peak demand in case of availability of PV and storage, and supplies all load demands when base power supplying units do not have enough power. A step down three phase transformer is used to deliver the load via controlled rectifier backed by dc-dc onverter to improve power factor. kVA rating of transformer is to be equivalent to peak power demand from the grid. For the simulation, three phase voltage source of 240V has been used as a grid.

2.2 Modeling of EV loads

The load demand in the charging station varies continuously and accurate load forecasting is very difficult as the load demand by the EV depends on many factors including activities and driving pattern of vehicle owner. Furthermore, instantaneous power demand depends on the numbers of simultaneous EVs plugged in a typical day is assumed to be varying as shown in Figure 1 [9].

The load modeling is based on the experiment data of a typical march day as presented in [10]. It shows the variation of number of electrical vehicles with time of a day. It shows that the EV load is maximum between 7:00 pm to 9:00 pm. The station has capacity to charge up to 15 EVs at a time.

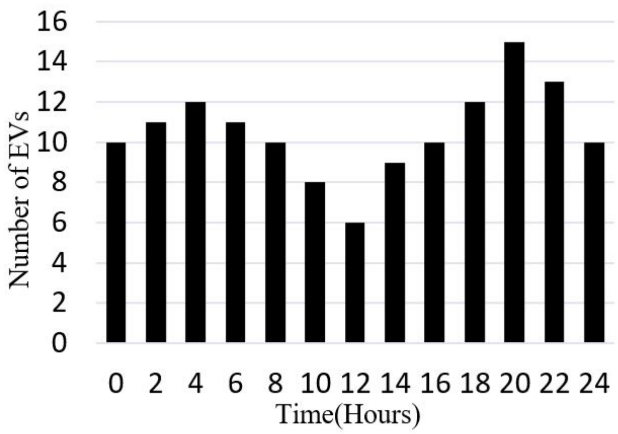

Figure 1: Number of EVs plugged in a typical day

Table 1: EV specification

Electric vehicle model	Nissan Leaf
Battery Type and Energy	Li-ion 24kWh
All-electric range	118 Km
Charging/discharging efficiency (Level 2 charging)	92 %
Power rating	4kW

The specifications of each electric vehicles are taken from reference [9]. Here, level 2 charging of battery is used in which the EV is provided with 240 V dc input and current of 15A. Table 1 represents the specifications of the EVs.

3. Proposed Framework for EV Load Sharing Among PV, BESS and Grid

This paper develops a system framework showing the electrical connection among the sources (PV, Battery and the grid) and the loads (EVs) charging stations, AC loads and DC loads). Figure 2 clarifies basic requirement for the system proposed in this research. It consists of a grid tied PV with battery. The PV array is connected to the dc link via dc/dc converter known as the dc booster in order to support the faster charging. BESS is used to deliver the part of peak load which significantly reduces the stress on the grid during peak time. Next, the battery energy storage system can supply the electrical power to the DC-link through the boost converter. The grid electricity is also fed to the DC-link via AC/DC converter. This way the DC-link is fed with three sources.

A suitable power management technique has been proposed to prioritize the source of electrical power to the charging stations. First priority would be the PV source. Second priority would be the battery energy storage system. The major advantage of using battery energy storage system is that it can store electrical energy from the grid at the time of the day when the electricity tariff is low and supplies the load in the time when electricity tariff is high to reduce overall energy cost of the charging station. The charging posts are fed with electric power through the dc link. The number of charging posts in a station depends upon the capacity of the station.

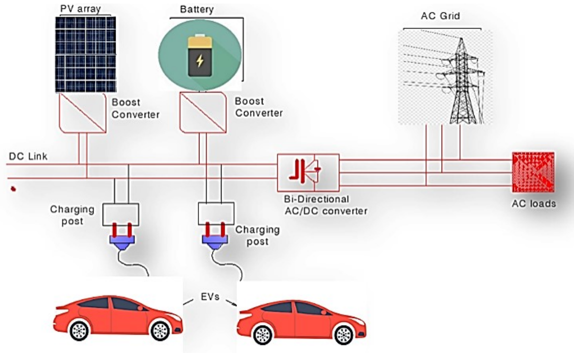

Figure 2: Proposed System Framework

3.1 Electric Vehicle Charging

Existing PEV charger hardware and technologies allow charging at either coordinated or uncoordinated manner. Uncoordinated charging strategy is used as it allows charging of EV at charger power rating continuously [11]. Once an EV is parked in charging station and is plugged in for charging, kWh demand of EV depends on its SOC level and is equivalent to following relation [9]:

$$E_{ch,i} = \frac{(1-SOC_{initial,i})C_{B,i}}{\eta} \tag{1}$$

Where, $E_{ch,i}$ is the charging kWh demand by the EV, $SOC_{initial,i}$ is the state of charge at the time of arrival,$C_{B,i}$ is the nominal battery capacity, and η is on-board charger efficiency. Total time taken for full charge of battery of EV after it is plugged in is estimated as [9]:

$$T_{ch,i} = \frac{E_{ch,i}}{P_{i,rated} * \eta} \tag{2}$$

Where, Pi, rated is the rated power (kW) of ith EV.

3.2 Load sharing in parallel connected sources

All change in the terminal voltage of the converters is carried out as per the load to be shared by their corresponding sources, and it's called droop regulation. Load sharing is modeled based on the interpolation of the droop characteristics as per the percentage load to be shared. Figure 3 shows the droop characteristics of the PV when all the sources are on. It shows the variation of change in voltage as per the load to be shared. Based on the interpolation from the curve for the required sharing of load, the value of droop regulation is found out.

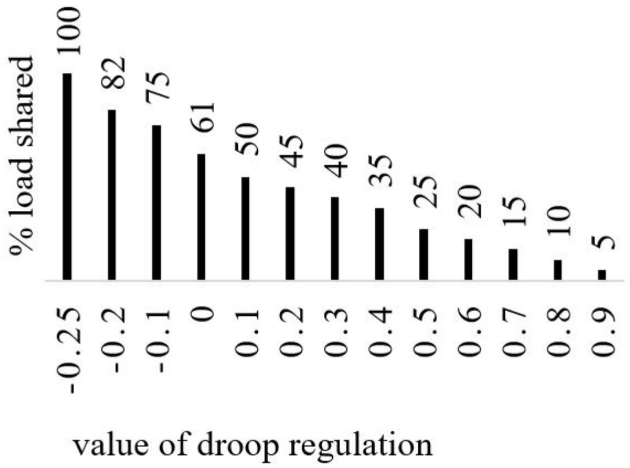

Figure 3: Variation of droop regulation of with % load shared by PV when PV and Grid are ON

When the converters are connected in parallel, they share load in accordance with their voltage output and overall resistance of the converter. When load is switched on/off suddenly, there is mismatch in converter output voltage because each converter tries to deliver the load. Which is why, the circulating current will increase significantly, as each converter switch try to increase the share of current and this causes overloads in converters.

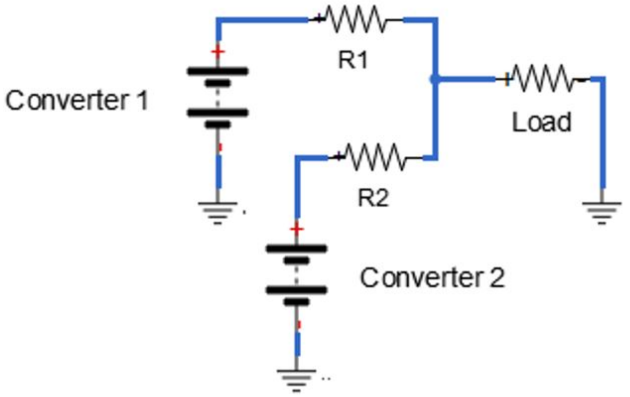

Figure 4: Two Parallel Connected Converters [8]

Figure 4 shows a simplified diagram of two parallel connected converters. Output voltages, currents and resistances of the converter-1 and converter-2 are represented by V_{dc1} andV_{dc2} , $I_1$and I_1, and $R_1$and R_1 respectively. By applying Kirchhoff's Voltage law in converter circuits, following relations can be established [8].

$$V_{dc1} - I_1R_1 - I_LR_L = 0 \tag{3}$$

$$V_{dc2} - I_2R_2 - I_LR_L = 0 \tag{4}$$

Expressions for output currents from each converter can be derived from above equations as [8]

$$I_1 = \frac{(R_2 + R_L)V_{dc1} - R_LV_{dc2}}{R_1R_2 + R_1R_L + R_2R_L} \tag{5}$$

$$I_2 = \frac{(R_1 + R_L)V_{dc2} - R_LV_{dc1}}{R_1R_2 + R_1R_L + R_2R_L} \tag{6}$$

$$I = I_1 + I_2 \tag{7}$$

The circulating current and overload load to the converter can be minimized by adding a droop regulation resistor R droop to each converter. By adding Rdroop1 and Rdroop2 in series with each converter, current sharing by individual converter can be improved. Droop resistor decreases the terminal voltage of each converter and minimizes the mismatch in current sharing. Droop regulation is implemented by adding or subtracting value, equivalent to droop resistor voltage drop, from the reference voltage given to each converter's PID controller so that it could fix the output voltage of each converters in accordance with the percentage of load to be shared by them.

Value of reference voltage of each PID controllers is calculated as [12]

$$V_{ref1} = -m_1P_1 + V_{NL} \tag{8}$$

$$V_{ref2} = -m_2P_2 + V_{NL} \tag{9}$$

Where, V_{NL} is the no load constant voltage, m_1 and m_2 are droop regulations obtained from slope of the voltage vs power plot. Value of m_1 and m_2 are calculated continuously as per the change in load demand by using interpolation method in which slope of droop characteristics is calculated according to the load to be shared. Here, m_1P_1 and m_2P_2 is the value of voltages to be changed ($\triangle V_1$ and $\triangle V_2$). Value of$\triangle V_1$ and $\triangle V_2$are formulated from the characteristics of % load vs$\triangle V$.

3.3 Power Flow management algorithm

Load demand of EV keeps on changing with time. For the different power demands PV, battery and Grid are scheduled using the algorithm as per the flow chart shown in Figure 5 [7]. It shows priority wise selection of sources either alone or in combination depending on the loads. Algorithm is simulated so as to provide highest priority to PV and it goes on decreasing from Battery to Grid. Scheduling is done such that PV power is fully utilized and so like for battery according to priority.

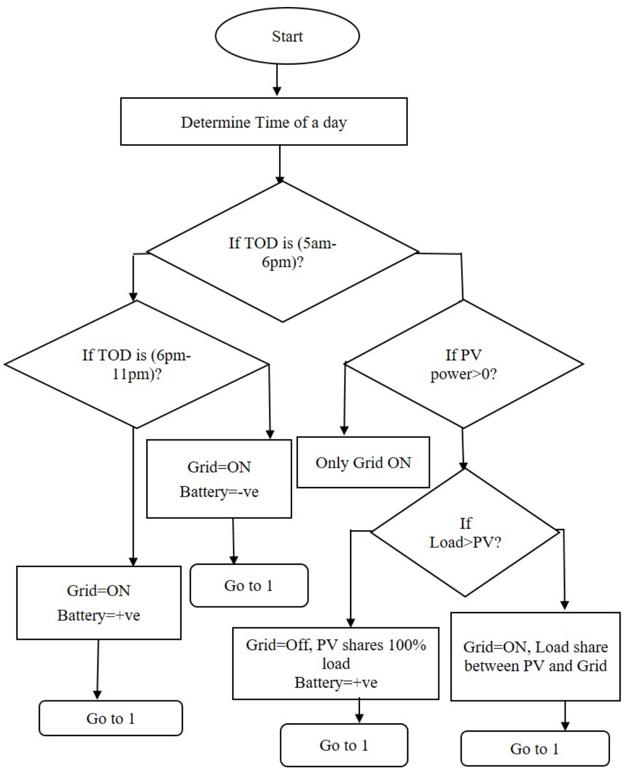

Figure 5: Flow chart of Power Management

For a specific load, the combination of sources to supply the load demand depends on the time of a day. During the day time (5am-6pm), solar energy is available for the power generation from PV and its power generation also varies with time due to the variation of temperature and irradiances with time of day. PV power generation is compared with the load demand. If EV power demand is higher than PV can provide, then Grid is made ON and PV shares load with Grid. Similarly, if Load demand at a specific time is less than PV power generation at that time, PV solely supplies the demand. Also, the PV power remained after supplying EV loads is utilized to charge the BESS. During the night time (11pm-5am), the Grid electricity tariff is lowest and hence BESS is charged at that time. Since, no power is generated from PV during night, so Grid supplies EV loads as well as BESS charging load. During the peak load demand time (6pm-11pm), there is no PV power generation, and there is large stress on the Grid due to high power demand from EVs. Also, the Grid electricity tariff is very high, that's why fully charged BESS is discharged to share load with Grid. By following the algorithm, continuous power availability for uncoordinated charging of EVs is implemented.

4. Results and Discussions

The proposed topology is simulated in MATLAB. EV load profile at different times of days is the key point for the selection of sources for the supply of their demand. The algorithm modeled in MATLAB determines the sources to be made on at certain time.

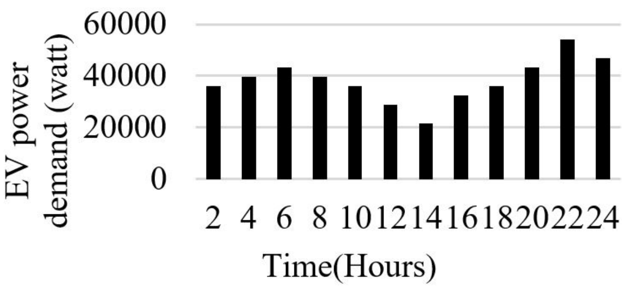

Figure 6: Estimated power demand by EVs in a typical day

Figure 6 shows the estimation of load demand by EVs at a particular day. The peak demand of EV is assumed to be 54KW from 7:00 pm to 9:00 pm in a typical day. The base load is assumed to be 28KW. So, the rating of PV and BESS is chosen 28KW each.

Figure 7 represents the variation of power generation from PV over the day based on temperature and irradiance data. It shows that PV generates maximum power of 28 kW during the mid-day which is equal to the base load required to be supplied. In other time there is no power generation from PV.

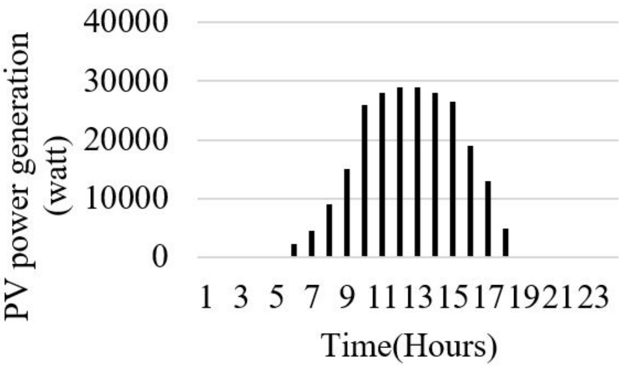

Figure 7: PV power generation during a typical day

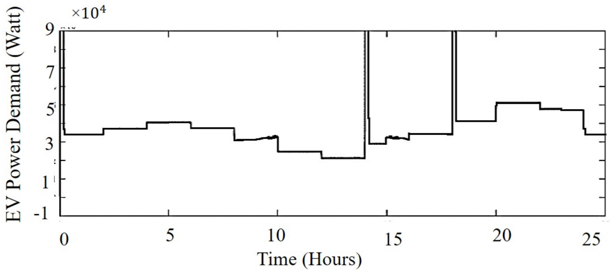

Figure 8: Actual power consumed by EV load

Figure 8 shows the active power demand of the EVs at different hours in a day. The demand is more in the morning and the evening when the expected commutation is also more.

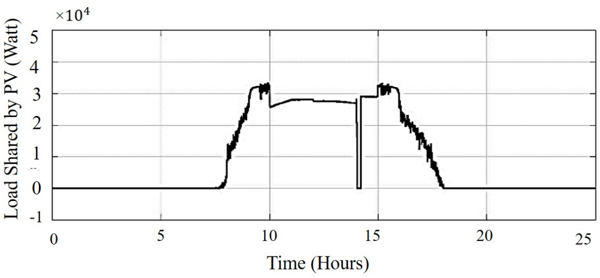

Figure 9: Load shared by PV

Figure 9 illustrates the load shared by PV for charging of EV during a typical day. It shows that when solar energy is available during the day time, then most part of the load is shared by PV. PV delivers all its power generation for charging of EVs as well as BESS is charged with excess power of PV.

Figure 10 represents the load profile of BESS, which illustrates the charging and discharging power profile of energy storage system. It illustrates that the BESS is charged during the off-peak time when tariff rate is significantly lower (between 11pm-5am). Charging can also be performed from PV power in the day time

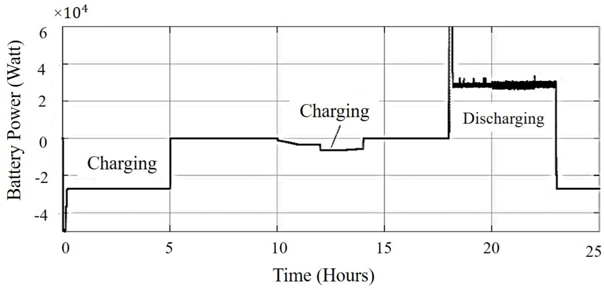

Figure 10: Charging and Discharging of BESS

when the load power is less than PV power. It is discharged during peak hours from 6:00pm to 11:00 pm in order to reduce the stress on the grid.

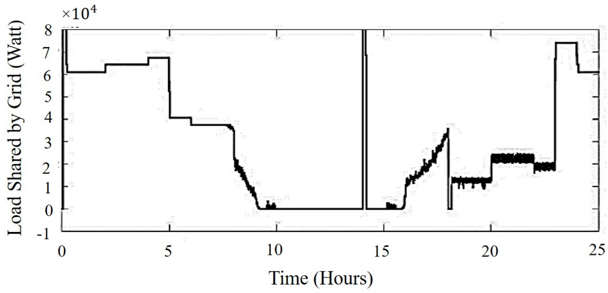

Figure 11: Load Shared by Grid

As shown in Figure 11, in the time when PV power is not sufficient to provide the load demand, Grid combines with the PV and shares the load with PV. It shows that Grid power input is maximum during midnight time when the electricity tariff is low. On the other hand, Grid power input is significantly small during peak load demand time and very small during day time when PV power is available.

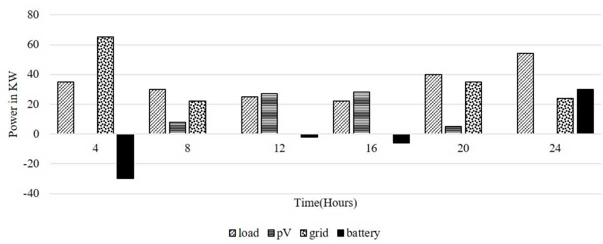

Figure 12: Load profiles of EVs, PV, BESS and Grid

Figure 12 shows the load profiles of sources. It shows in the very morning; Grid power supply is greater than EV demand. This indicates extra power from the grid is used to charge BESS. Here, negative power indicates charging of battery. During the peak hours, BESS is given more priority to supply the load, i.e. base load 28KW is supplied by battery and remaining load is supplied by the Grid. In the figure, positive BESS power represents the discharging of BESS, whereas negative power indicates the charging of battery. Likewise, in the mid-day, Grid power is very small or zero due to high power contribution by PV. In the peak load demand, BESS shares significant loads and hence reduces the stress in the grid. The simulation results clarify that EV load demands are fulfilled by prioritizing the sources on the basis of power management algorithm.

5. Conclusions

Proposed power flow management techniques for charging of electric vehicle has been presented in this paper. The objective of the proposed technique is to design a topology which supports fast charging of electric vehicles by the penetration of PV, and BESS into the grid, which significantly reduces the stress in the grid due to fast charging. The proposed idea is implemented by modeling EV loads profiles and prioritizing the sources accordingly in order to fulfill all the power demand of the EV loads. This supports uncoordinated method of charging of electric vehicles. Application of droop regulation method is implemented for the effective load sharing by different sources. The whole system is simulated in MATLAB and verified the effectiveness of the system under various load conditions. This work focuses on the penetration of renewable energy sources onto the grid for EV charging. This can reduce the effects on the electricity grids, which is caused by high power consumption for fast charging of EVs.

References

[1] Alireza Aslani. Strategic variables of commercialization of renewable energy technologies. *Journal of Renewable and Sustainable energy*, 7(2):023105, 2015.

[2] Nuh Erdoğan, Fatih Erden, and Tuncay Altun. Coordinated electric vehicle charging strategy in microgrids containing pv system. *Gazi University Journal of Science Part A: Engineering and Innovation*, 4(1):9–21, 2017.

[3] Javier García-Villalobos, I Zamora, JI San Martín, FJ Asensio, and V Aperribay. Plug-in electric vehicles in electric distribution networks: A review of smart charging approaches. *Renewable and Sustainable Energy Reviews*, 38:717–731, 2014.

[4] Mohamed O Badawy and Yilmaz Sozer. Power flow management of a grid tied pv-battery system for electric vehicles charging. *IEEE Transactions on Industry Applications*, 53(2):1347–1357, 2016.

[5] Azhar Ul-Haq, Marium Azhar, Yousef Mahmoud, Aqib Perwaiz, and Essam Al-Ammar. Probabilistic modeling of electric vehicle charging pattern associated with residential load for voltage unbalance assessment. *Energies*, 10(9):1351, 2017.

[6] Chouki Balakishan, N Sandeep, and MV Aware. Design and implementation of three-level dc-dc converter with golden section search based mppt for the photovoltaic applications. *Advances in Power Electronics*, 2015, 2015.

[7] A Hassoune, M Khafallah, A Mesbahi, and T Bouragba. Power management strategies of electric vehicle charging station based grid tied pv-battery system. *International Journal of Renewable Energy Research*, 8(2):851–860, 2018.

[8] Pushkar Chaudhari, Mayuresh Khadse, Vinaya Jadhav, Prachi Patil, Kaustubh Daware, Mukta Rajwade, and Shobhit Sharma. Novel control strategy for dynamic load sharing between dc-dc converters for dc microgrid. In *2015 IEEE International Conference on Signal Processing, Informatics, Communication and Energy Systems (SPICES)*, pages 1–5. IEEE, 2015.

[9] Menaka Karki and Jai Govind Singh. An approach to enhance the life of transformer and the battery of gridable vehicles. In *2018 5th IEEE Uttar Pradesh Section International Conference on Electrical, Electronics and Computer Engineering (UPCON)*, pages 1–8. IEEE, 2018.

[10] Kuihua Wu, Xinsheng Niu, Jian Wang, Kuizhong Wu, and Shanjie Jia. Electric vehicle load characteristic analysis and impact of regional power grid. In *2nd International Conference on Electronic & Mechanical Engineering and Information Technology*. Atlantis Press, 2012.

[11] Ke Zhang, Yuming Mao, Supeng Leng, Yejun He, Sabita Maharjan, Stein Gjessing, Yan Zhang, and Danny HK Tsang. Optimal charging schemes for electric vehicles in smart grid: A contract theoretic approach. *IEEE Transactions on Intelligent Transportation Systems*, 19(9):3046–3058, 2018.

[12] Reshma Mary Thomas and Deepu Jose. Control method for parallel dc-dc converters used in standalone photovoltaic power systems. *Int. J. Energy Res. Technol*, 4:784–789, 2015.